18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18)
Beijing, China, August 7-12, 2005
SMiRT18-D03-8

PIPING VIBRATION STRESS MEASUREMENT AND LIFE ASSESSMENT

Nianwen Lu, Xiaolong Wang, Xiaozhen Wu
Suzhou Nuclear Power Institute (SNPI), China

ABSTRACT

In Lingao Phase 1 nuclear power plant, violent piping vibration was found during the function test of the pump, especially when the pump was run under small flow. The authors of this article measured the dynamic stress of the piping with strain gauges and gave a fatigue life assessment of the piping with ASME and BS codes.

KEYWORDS: piping, vibration stress, fatigue life assessment

INTRODUCTION

During the functional tests of the Lingao Phase 1 nuclear power plant, violent vibration was found on the suction piping of electrical pump of the auxiliary feedwater system (ASG system) under small flow. The piping materials are carbon steels operated at room temperature with a very low internal pressure. Framatome ANP measured the vibration velocities of the piping on some selected points. According to their report, the maximum vibration velocity of a point reached 40mm/s RMS (Root of Mean Square), and the allowed velocity was 24mm/s RMS, which would assure a fatigue life of 10^{11} cycles. Apparently, the measured vibration level on ASG piping was too high to validate continuous operation for an infinite duration fatigue life [1].

The Framatome ANP report used ASME-OM Standard to assess the piping vibration level. In fact, ASME-OM gives a method to indirectly assess the vibration stress through the measurement of vibration velocity. But there are some uncertainties in this method, e.g. factor for concentrated mass correction, shape factor and peak factor, etc. It is somewhat difficult to decide these factors accurately [2].

To acquire the real stresses distribution and their variations with the time along the whole piping, SNPI measured the vibration stresses with strain gauges and gave a general assessment of residual life of the piping.

SELECTION OF MEASUREMENT POINTS

Strain gauges were placed on the following locations of the piping:

- Short “Z” bend, on the mid-plane at the out-surface of the flank
- Near branch connection
- Elbow near the pump
- Straight pipe adjacent to pump suction

In general, places were selected where stress concentration existed and perhaps the maximum bending moment existed.

VIBRATION CHARACTERISTICS OF THE PIPING

10 sets of vibration strain data were collected with a continuous measuring time of 6 minutes for each set. Piping vibration had some characteristics as follows:

- Nearly no vibration when the flow rate was above 30 m^3/h.
- No vibration if the feedwater control valve was always shutoff.
- Significant vibration existed when opening the control valve at a flow rate of 15 m^3/h.
- Most significant vibration appeared when switching the control valve from opening to shutoff condition, i.e. maximum vibration at near 0 m^3/h flow rate.

LIFE ASSESSMENT METHOD

After checking the collected data it was found the straight pipe near pump suction had the maximum vibration strain level under the condition of 0 m^3/h. The next was the short Z bend. It was found through field observation that the piping had a regular in-plane vibration without any stochastic rotation. Therefore it was simply assumed that the stress status was bilateral on outside diameter of the straight pipe, with both axial and hoop stress as principal stress. For the Z bend, the principal stresses must be measured and calculated with rosette gauge. The life assessment procedures were listed bellow [3]:

(1) Translating the strains collected during 6 minutes into principal stresses with Poisson's ratio taken as 0.3 and Young's elastic modulus as 210Gpa.

(2) Calculating the stress differences of every point on the cyclic stress wave.

(3) Derivation of alternating stress intensity.

(4) Counting the total cycling numbers of the vibration during 6 minutes.

(5) Calculating the cumulative fatigue usage (CUF) in 6 minutes at 0 m^3/h according to the ASME code.

RESULT OF ALTERNATING STRESS INTENSITY AND CUF OF STRAIGHT PIPE

According to the calculation, the highest alternating stress intensity during 6 minutes was

$$S_{alt}\ (max) = 40.7\ Mpa$$

Vibration waves appeared like sine waves and the total cycles counted reached a number of 8819. A further counting was then carried out according to the ratio of the alternating stress intensity to the S_{alt} (max) in a descending order, i.e. counting the number of wave cycles in between 1.0 S_{alt} (max)~0.98 S_{alt} (max), then counting the number of wave cycles in between 0.98S_{alt} (max)~0.96S_{alt} (max)… and so on. Finally the cumulative fatigue usage in 6 minutes was calculated with ASME code and British code design fatigue curves.

General notes

a. Stress intensity should be multiplied by following factors when to be used in the applicable design fatigue curve. Since there was an as-welded butt weld on the straight pipe, the fatigue strength reduction factor must be considered. In this case, a worst situation was assumed. The as-welded butt weld was treated as a fillet weld in a conservative way. For this type of weld, the BS5500 recommends a fatigue reduction factor of 2.5 and the ASME BPV SECTION 3 gives a factor of 4.0[3][4].

b. For BS5500, when stress intensity was bellow 33Mpa, the allowed number of cycles would be more than 5×10^6, the fatigue damage will not be considered. For ASME code, it is 48Mpa under which the calculation would be stopped.

Results

According to the BS5500, under 0m^3/h flow rate, the consumed fatigue usage in 6minutes was

$$\Sigma d=362.207\times10^{-5}$$

See table 1.If the total fraction of life was 1.0; the allowed continuous operating time would be 1656 minutes.

At the same time, the results of allowed continuous operating time would be 3180 minutes when using ASME code. The detailed calculation was omitted.

Table 1 S_{alt} (max) = 40.7 MPa Consumed fatigue usage according to BS5500

Ratio of S/ S_{alt} (max)	Stress intensity S(MPa)	Stress intensity of as-welded butt weld S' (MPa)	Fatigue usage per cycle	Number of wave cycles in 6 minutes	Usage in 6 minutes
100% - 98%	40.7	101.8	$1/(1.0\times10^5)$	2	2.000×10^{-5}
98% - 96%	39.9	99.8	$1/(1.1\times10^5)$	2	1.818×10^{-5}
96% - 94%	39.1	97.8	$1/(1.2\times10^5)$	1	0.833×10^{-5}
94% - 92%	38.3	95.8	$1/(1.4\times10^5)$	1	0.714×10^{-5}
92% - 90%	37.5	93.8	$1/(1.5\times10^5)$	0	0000×10^{-5}
90% - 88%	36.6	91.5	$1/(1.6\times10^5)$	3	1.875×10^{-5}
88% - 86%	35.8	89.5	$1/(1.7\times10^5)$	3	1.764×10^{-5}
86% - 84%	35.0	87.5	$1/(1.8\times10^5)$	6	3.333×10^{-5}
84% - 82%	34.2	85.5	$1/(1.9\times10^5)$	9	4.736×10^{-5}
82% - 80%	33.4	83.5	$1/(2.1\times10^5)$	16	7.619×10^{-5}
80% - 78%	32.6	81.5	$1/(2.4\times10^5)$	17	7.083×10^{-5}
78% - 76%	31.8	79.5	$1/(2.6\times10^5)$	28	10.769×10^{-5}
76% - 74%	30.9	77.3	$1/(2.8\times10^5)$	21	7.500×10^{-5}
74% - 72%	30.1	75.3	$1/(3.2\times10^5)$	26	8.124×10^{-5}
72% - 70%	29.3	73.3	$1/(3.4\times10^5)$	39	11.470×10^{-5}
70% - 68%	28.5	71.3	$1/(3.6\times10^5)$	61	16.944×10^{-5}
68% - 66%	27.7	69.3	$1/(4.2\times10^5)$	76	18.095×10^{-5}
66% - 64%	26.9	67.3	$1/(4.6\times10^5)$	91	19.782×10^{-5}
64% - 62%	26.1	65.3	$1/(5.0\times10^5)$	134	26.800×10^{-5}
62% - 60%	25.2	63.0	$1/(5.6\times10^5)$	151	26.964×10^{-5}
60% - 58%	24.4	61.0	$1/(6.0\times10^5)$	164	27.333×10^{-5}
58% - 56%	23.6	59.0	$1/(7.0\times10^5)$	178	25.428×10^{-5}
56% - 54%	22.8	57.0	$1/(8.0\times10^5)$	184	23.000×10^{-5}

54% - 52%	22.0	55.0	$1/(9.0\times10^5)$	193	21.444×10^{-5}
52% - 50%	21.2	53.0	$1/(10.5\times10^5)$	218	20.761×10^{-5}
50% - 48%	20.4	51.0	$1/(12.0\times10^5)$	199	16.583×10^{-5}
48% - 46%	19.5	48.8	$1/(14.0\times10^5)$	151	10.785×10^{-5}
46% - 44%	18.7	46.8	$1/(16.0\times10^5)$	153	9.562×10^{-5}
44% - 42%	17.9	44.8	$1/(18.0\times10^5)$	150	8.333×10^{-5}
42% - 40%	17.1	42.3	$1/(21.0\times10^5)$	119	5.666×10^{-5}
40% - 38%	16.3	40.8	$1/(25.0\times10^5)$	117	4.680×10^{-5}
38% - 36%	15.5	38.8	$1/(31.0\times10^5)$	115	3.709×10^{-5}
36% - 34%	14.7	36.8	$1/(40.0\times10^5)$	131	3.275×10^{-5}
34% - 32%	13.8	34.5	$1/(46.0\times10^5)$	157	3.413×10^{-5}
Total fatigue usage in 6 minutes					$\Sigma d=362.207\times10^{-5}$

CONCLUSIONS

(1) There were two factors leading to the conservative results of the life assessment:

a. The as-welded butt weld was treated as a fillet weld, hence the stress intensity may be conservatively enlarged

b. Rain flow method was not be used in assessment leading to the conservatism of the cycle counting

(2) The result of BS5500 was more conservative than ASME code because the difference between two types of design fatigue curves

(3) In worst case, the continuous operating time of the piping could last at least 1635 minutes

REFERENCES

1. Framatome ANP, 2 ASG 001 piping line vibrations, Authors: Alain Boulan and Francis Le Breton, No. LA/DP 02.0068.
2. ASME OM-S/G-2000, Part 3 Requirements for Preoperational and Initial Start-up Vibration Testing of Nuclear Power Plant Piping Systems.
3. ASME BPV SECTION III, Division 1 Subsection NB-3200, 1998 Edition.
4. BS5500 APPENDIX C Recommendations for the assessment of vessels subject to fatigue, 1994 Edition.